

Integration of Acoustic Neutrino Detection Methods into ANTARES¹

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Abstract. The ANTARES Neutrino Telescope [1] is a water Cherenkov detector currently under construction in the Mediterranean Sea. It is also designed to serve as a platform for investigations of the deep-sea environment. In this context, the ANTARES group at the University of Erlangen will integrate acoustic sensors within the infrastructure of the experiment. With this dedicated setup, tests of acoustic particle detection methods and deep-sea acoustic background studies shall be performed. The aim of this project is to evaluate the feasibility of a future acoustic neutrino telescope in the deep sea operating in the ultra-high energy regime. In these proceedings, the implementation of the project is described in the context of the premises and challenges set by the physics of acoustic particle detection and the integration into an existing infrastructure.

1. Introduction

Towards the detection of neutrinos with energies exceeding 100 PeV, the use of acoustic pressure waves produced in neutrino-induced cascades is a promising approach. One advantage of acoustic waves is the absorption length of the order of 1 km for the peak spectral density of the generated sound waves around 20 kHz [2]. To investigate the feasibility of building a detector in the deep sea based on this method, it is necessary to understand the acoustic background conditions and characteristics of transient noise sources in detail on a long time scale. Especially the rate and correlation length of neutrino-like acoustic background events is not known and yet is a prerequisite for the estimation of the sensitivity of such a detector. The aim of the project described here is to measure the acoustic conditions of the deep-sea environment at the ANTARES site with a dedicated array of custom-designed acoustic sensors at different distances.

Towards this goal several additional basic detector elements (*storeys*, cf. Sec. 2) of the ANTARES neutrino telescope will be equipped with acoustic sensors. On these storeys the sensors will substitute the optical sensors (photo-multiplier tubes, *PMTs*) used for Cherenkov detection of neutrinos. Several components of the ANTARES infrastructure have to be modified or substituted to integrate the acoustic sensors into the ANTARES data acquisition (*DAQ*) scheme. In these proceedings the changes will be described, and an overview of the project will be given (cf. also [3]).

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2. The ANTARES detector

The ANTARES detector [1] is currently installed in the Mediterranean Sea, 40 km off the coast of Toulon (southern France) in a water depth of up to 2500 m. Its completion is foreseen in 2007; the neutrino telescope will then consist of 12 vertical structures (*detection lines*) with a total of 900 optical sensors for the detection of Cherenkov light of neutrino interaction secondaries. Each line is fixed to the sea bed by an anchor and held vertically by a buoy on the top. A detection line has a total height of 480 m and comprises 25 storeys spaced evenly within the instrumented height of 350 m. The 12 lines are placed on the sea floor in an octagonal shape with 4 lines in a quadratical layout in the centre. The distance between two neighbouring lines ranges from 60 m to 80 m, covering a total area of approx. $180 \times 180 \text{ m}^2$ on the sea-floor. An extra 13th line - the Instrumentation Line (*IL*) - will be equipped with sensors to monitor environmental parameters and with devices to calibrate the detector. The detector is connected to the on-shore control room via deep-sea cables providing electrical power and data transmission. At the writing of these proceedings, two detection lines and a progenitor of the IL are installed at the site and operated successfully.

A sketch of the complete ANTARES detector with the acoustic addition described in Sec. 4 is shown in Fig. 1.

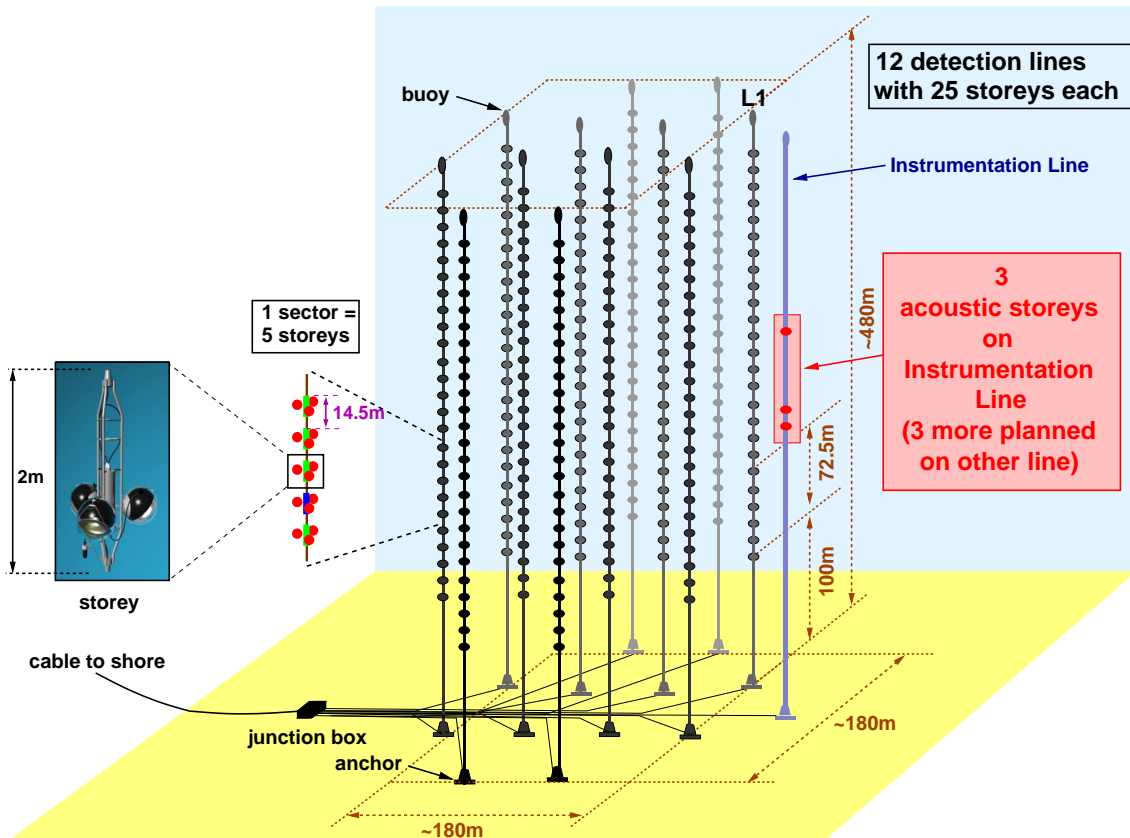


Figure 1. Sketch of the ANTARES detector with the addition for acoustic studies. For further description see text.

An optical storey (cf. Fig. 2) constitutes the basic detection element of the ANTARES detector and consists of three Optical Modules (*OMs*) (optical sensors in a pressure-resistant glass housing), a Local Control Module (*LCM*) (for data acquisition-, control- and monitoring hardware) and miscellaneous auxiliary devices on a mechanical support frame.



Figure 2. An ANTARES storey equipped with three optical sensors in glass spheres and a container for electronics (Titanium cylinder in the middle) attached to a Titanium support structure. Visible at the lower left is a hydrophone used for the determination of the storey position.

3. Aim of the Acoustic Studies in ANTARES

Neutrinos interacting in water deposit energy in a cascade of secondary particles. According to the thermo-acoustic model developed by Askarian [4], the fast deposition and slow dissipation of the energy in the water in form of heat leads to a bipolar pressure pulse (*BIP*) [5]. The main frequency range of the generated sound waves spans from 1 to 100 kHz with a maximum spectral density around 20 kHz. It propagates through the medium in a flat disk shape perpendicular to the main axis of the cascade.

Given the expected low flux of neutrinos with energies in excess of 100 PeV, a potential acoustic neutrino telescope not only must have very large dimensions, but must be operated basically background-free. It is therefore of great importance to understand the acoustic background due to BIPs from noise sources in the deep sea, which could mimic neutrino signatures in a future detector. The measurement of the rate of BIP signals as a function of pressure amplitude and volume is therefore decisive to assess the feasibility of acoustic neutrino telescopes and to determine a realistic lower bound on the neutrino energy that is detectable.

The acoustic detection equipment in ANTARES is designed to perform such background measurements over a period of several years in a realistic arrangement of acoustic sensors. Simulations [6] suggest that an acoustic detector will not gain efficiency significantly when instrumented with more than 200 acoustic clusters (each consisting of several hydrophones, similar to the acoustic storeys in ANTARES) per km³. The resulting average distance between acoustic clusters is on the order of 200 m. This is comparable to the largest distance between acoustic storeys in ANTARES, as will be discussed in the next section.

4. The Acoustic Setup

Acoustic sensors will be integrated at three storeys on the IL, which will be installed at the ANTARES site in mid-2007. Each storey will be equipped with 6 sensors. The vertical distance for these storeys will be approx. 15 m and 100 m, resulting in – together with the sensor spacing of approx. 1 m within the storey – three different length scales for the investigation of acoustic background sources. Three additional acoustic storeys are planned on one further detection line at a horizontal distance exceeding 100 m.

4.1. The Acoustic Sensors

For the integration of acoustic sensors into the ANTARES experiment, the data acquisition system [7] has to be modified. This is done under the premise of preventing any interference with the optical data taking. To optimise resources and to make use of the well-tested existing system wherever feasible, as few changes as possible to the ANTARES design are targeted.

Major changes affect the storey, where the OMs are replaced by custom-designed acoustic sensors: hydrophones or so called acoustic modules (*AMs*) (cf. Fig. 4). These sensors are based on piezo-electrical ceramics that convert pressure waves into voltage signals, which are then amplified for read out [8]. The ceramics and amplifiers are coated in polymer plastics in the case of the hydrophones. For the AMs they are glued to the inside of a water-tight sphere. The latter non-conventional design was inspired by the idea to take the deep-sea water pressure from the piezo ceramics and electronics. The three acoustic storeys on the IL will house hydrophones only, whereas at least one of storeys planned in addition will house AMs.

All acoustic sensors are tuned to be sensitive over the whole frequency range of interest (typically around $-145 \text{ dB re } 1 \text{ V}/\mu\text{Pa}$) and to have a low noise level [9]. The sensitivity of a prototype hydrophone with approx. 10 dB less gain than the final sensor design is shown in Fig. 3. Artist's views of the storeys with different acoustic sensors are shown in Fig. 4.

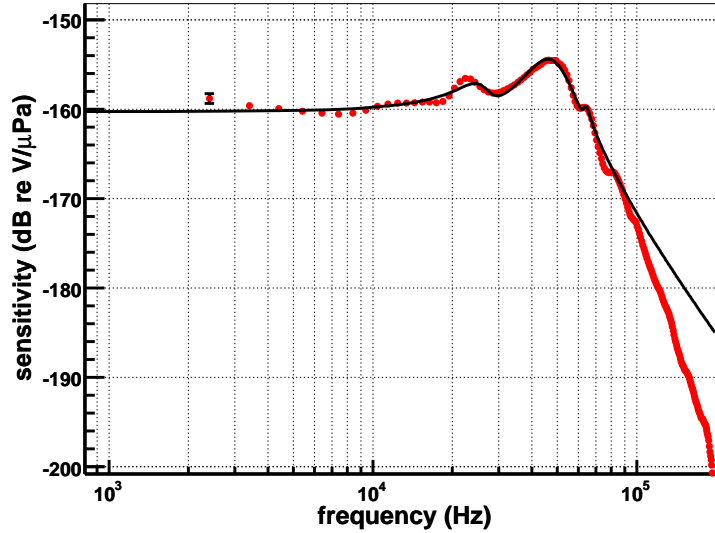


Figure 3. Sensitivity plot of a prototype hydrophone with measured data points and a model fit [8] (solid line) in the frequency range from 1 to 250 kHz on a logarithmic scale. The model does not include the frequency response of the amplifier in the sensor, which is responsible for the discrepancy at higher frequencies.

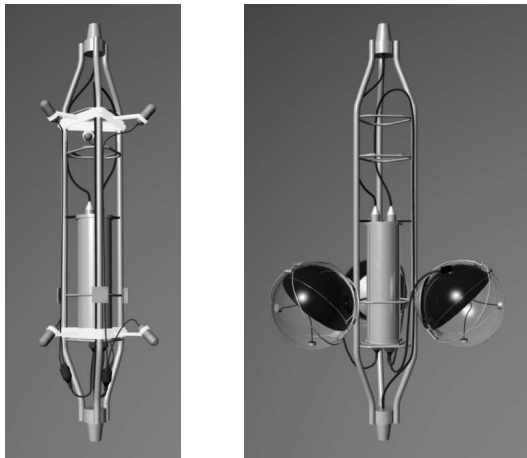


Figure 4. Artist's views of acoustic storeys resulting from the replacement of OMs by six hydrophones (left) or three acoustic modules housing two piezo sensors each (right).

4.2. The Acoustic Data Acquisition

In the ANTARES DAQ scheme the digitisation is conducted within the LCM on each storey by several custom-designed electronics boards, which send as much unfiltered data as possible to shore. With its capability of timing resolutions on a nanosecond-scale and synchronous transmission of several MByte per second and storey, it is perfectly suited for the acquisition of acoustic data. Additionally, the ANTARES infrastructure provides measurements of the position of the storey with a precision better than 10 cm and of miscellaneous environmental parameters (e.g. the speed of sound, temperature and sea current). For the digitisation of the acoustic signals and feeding into the ANTARES data stream the so-called acoustics digitisation board (*AcouADC-board*) was designed. There are a total of three such boards per storey receiving the data of two sensors each.

4.3. The AcouADC-Board

The AcouADC-board consists of an analogue and a digital part. The analogue part amplifies the voltage signals coming from the acoustic sensors by adjustable factors between 1 and 512 and filters the resulting signal. The system has low noise and is designed to be – together with the sensors – sensitive to the acoustic background of the deep sea over a wide frequency-range (approx. 1 to 100 kHz).

Figure 5 shows the measured filter characteristics of the analogue part of a prototype AcouADC-board for a gain of 10 in amplitude (20 dB). In the left hand plot the frequency response of the integrated bandpass is observable. This filter suppresses frequencies below approx. 4 kHz and above approx. 130 kHz. The high-pass part cuts into the trailing edge of the low frequency noise of the deep-sea acoustic background [10] and thus protects the system from saturation. The low-pass part efficiently suppresses frequencies above the Nyquist frequency of 250 kHz for the digitisation frequency of 500 kHz (see below). For frequencies above roughly 10 kHz, the time delay of signals passing through the analogue part (right plot of Fig. 5) is negligible on the digitisation time scale of 2 μ s.

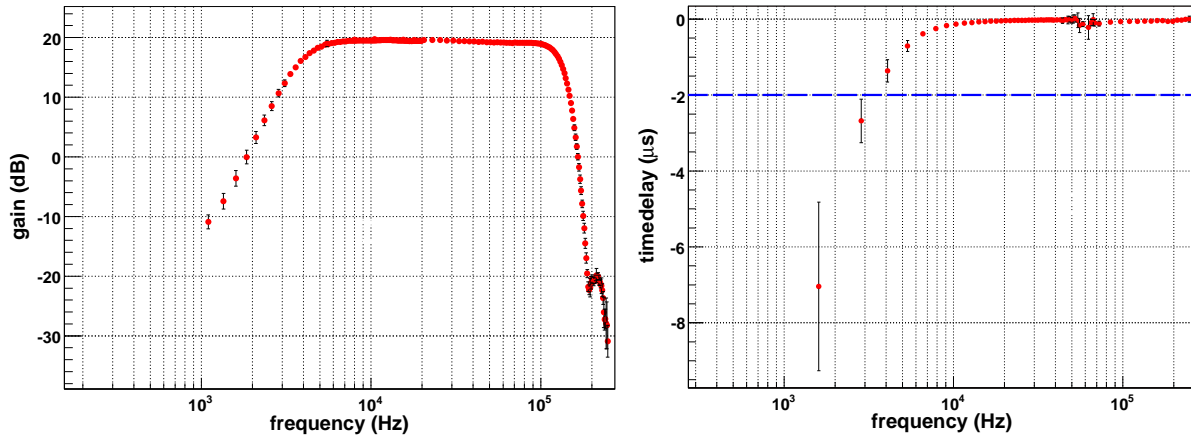


Figure 5. Measured filter characteristics of the analogue part of a prototype AcouADC-board in the frequency range from 1 to 250 kHz on a logarithmic scale. The left figure shows the amplitude gain in dB, the right one the time delay in μ s. The dashed line in the right-hand plot denotes the electronics digitisation time of 2 μ s, showing the characteristic time scale.

By the calibration of the whole data taking chain – the transfer function of the system – it is possible to reconstruct the acoustic signal from the recorded one with high precision within the sensitive frequency range of the setup. The dynamic range achieved is from the order of 1 mPa to the order of 10 Pa in rms over the frequency range from 1 to 100 kHz.

This allows for studying both the acoustic background in the deep sea under all prevailing conditions [10] and BIPs from noise sources mimicking neutrino signatures of energies exceeding e.g. GZK-neutrinos by several orders of magnitude.

The digital part digitises and processes the acoustic data. It is designed to be highly flexible by employing a micro controller (μC) and a field programmable gate array (*FPGA*) as data processor. The μC can be controlled from the on-shore control room and is used to adjust settings of the analogue part and the data processing. Also, the complete programming of the AcouADC-board can be updated in situ. The *FPGA* reads the digitised acoustic data from the analogue to digital converter (*ADC*) which has a 16-bit resolution and a maximum sampling rate of 500 kSamples per second (*kSPS*). The data is processed, e.g. down-sampled to reduce data traffic, and is read out by the ANTARES DAQ system which handles the transmission to the control room.

The maximum data rate per storey is limited to 20 Mbit per second by the electronics sending the data to shore, limiting the maximum sample rate of acoustic data per storey to 1.25 MSPS. Therefore the digital data is down-sampled to 200 kSPS at the AcouADC-board, to allow for continuous and synchronous read-out of all six sensors of each storey. However, the bandwidth can be distributed freely between the sensors, so transmission of the acoustic data is also possible for two sensors at each storey at full sampling-rate.

On-shore a dedicated PC-cluster will be set up to process and store the acoustic data arriving from the storeys and to control the off-shore DAQ. On this cluster, different data filtering schemes and triggers will be implemented, as well as raw data stored.

5. Summary and Outlook

A dedicated array of acoustic sensors will be installed in the deep-sea environment of the ANTARES site in 2007. The aim is to study the feasibility of a future neutrino detector in water employing the acoustic detection method. The technical realisation of the project is well advanced with prototypes of each component ready and tested. The setup will provide the possibility to study the acoustic background noise and signals of the deep sea on a long time scale in the frequency range of interest between 1 and 100 kHz. The main goal is to measure the rate of correlated neutrino-like background events on different length scales, which is decisive for assessing the sensitivity of a future acoustic detector for ultra-high-energy neutrinos.

References

- [1] ANTARES coll. 1999 A deep sea telescope for high energy neutrinos *Preprint astro-ph/9907432*
ANTARES homepage: antares.in2p3.fr
- [2] Fisher F H, Simmons V P 1978 *J. Acou. Soc. Am.* **62**(3) 558 - 64
- [3] Lahmann R, Anton G, Graf K, Höfl J, Kappes A, Karg T, Katz U, Naumann C and Salomon K 2006 *Proc. of the Int. Workshop (ARENA 2005)* (Singapore: World Scientific Publishing) 227-31
- [4] Askarian G A, Dolgoshein B A, Kalinovskiy A N and Mokhov N V 1979 *Nucl. Inst. Meth.* **164** 267-78
- [5] Graf K, Anton G, Graf K, Höfl J, Kappes A, Karg T, Katz U, Lahmann R, Naumann C, Salomon K and Stegmann C 2006 *Proc. of the Int. Workshop (ARENA 2005)* (Singapore: World Scientific Publishing) 127-31
- [6] Karg T 2006 Detection of ultra high energy neutrinos with an underwater very large volume array of acoustic sensors: A simulation study *Preprint arXiv:astro-ph/0608312*
- [7] Aguilar J A et al. 2006 The data acquisition system for the ANTARES neutrino telescope, accepted for publication in *Nucl. Inst. Meth. A* (*Preprint arXiv:astro-ph/0610029*)
- [8] Anton G et al. 2006 Study of piezo based sensors for acoustic particle detection, Article in Press *Astropart. Phys. (Online Version doi:10.1016/j.astropartphys.2006.07.001)*
- [9] Naumann C, Anton G, Graf K, Höfl J, Kappes A, Karg T, Katz U, Lahmann R and Salomon K 2006 *Proc. of the Int. Workshop (ARENA 2005)* (Singapore: World Scientific Publishing) 92-96
- [10] Urlick R J 1983 *Principles of underwater sound* (Los Altos, CA: Peninsula Publishing)